Nickel isotopic composition of Ryugu and the link between CI and other carbonaceous chondrites

T. Kleine F. Spitzer[1], C. Burkhardt[1], the Hayabusa2-initial-analysis chemistry team, and the Hayabusa2-initial-analysis core
[1]Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany

The initial analyses of samples returned from Cb-type asteroid 162173 Ryugu by JAXA's Hayabusa2 mission provided isotopic, mineralogical, and chemical evidence for a close link of Ryugu to CI chondrites [1,2]. A subsequent study has shown that Ryugu and CI chondrites share the same nucleosynthetic Fe isotope signatures, which are distinct from those of other carbonaceous chondrites [6]. This not only demonstrates that Ryugu and CI chondrites are genetically linked, but also that they derive from another reservoir than all other carbonaceous chondrites [3]. However, the origin of these distinct Fe isotopic compositions of CI chondrites/Ruygu compared to other carbonaceous chondrites is not well understood. Nickel isotopes hold considerable promise to further investigate the genetic link between Ryugu and CI chondrites. When normalized to $^{61}Ni/^{58}Ni$, CI chondrites do not only display the largest $\mu^{62}Ni$ and $\mu^{64}Ni$ anomalies among carbonaceous chondrites (where $\mu^{i}Ni$ is the parts-per-million deviation from terrestrial standard values), but they also have a distinct $\mu^{60}Ni$ composition compared to all other known carbonaceous chondrite-like materials. We obtained four Ryugu samples (A0106–A0107, A0106, C0108, C0107) along with six carbonaceous chondrites including the CI chondrites Orgueil and Alais, which have been chemically processed alongside the Ryugu samples [2]. In addition, we also measured several grouped and ungrouped carbonaceous chondrites. Chemical purification of Ni involved a 3-step ion-exchange chromatographic procedure that achieves sufficiently low $^{58}Fe/^{58}Ni$ and $^{64}Zn/^{64}Ni$ ratios in the final purified Ni cuts to allows for accurate and precise correction of isobaric interferences. All isotope measurements were performed on the Thermo Scientific NeptunePlus MC-ICP-MS at the Institut für Planetologie, University of Münster. Instrumental mass bias is corrected by internal normalization to either $^{61}Ni/^{58}Ni$ or $^{62}Ni/^{61}Ni$ using the exponential law. All data are reported in the μ-notation as the parts per 10^6 deviation relative to the standard.

The new Ni isotopic data for CM, CO, CV, and CR chondrites agree well with those reported in previous studies and reveal that these chondrites are characterized by negative $\mu^{60}Ni$ and positive $\mu^{62}Ni$ and $\mu^{64}Ni$ values (Fig. 1). The two ungrouped carbonaceous chondrites Tagish Lake (TL) and Tarda, for which no Ni isotopic data have been reported previously, have Ni isotope anomalies similar to those carbonaceous chondrites. By contrast, CI chondrites display distinct Ni isotopic compositions and particular distinctly larger $\mu^{64}Ni$ and $\mu^{60}Ni$ compared to other carbonaceous chondrites (Fig. 1). Importantly, the Ni isotopic compositions of all four Ryugu samples overlaps with those of the CI chondrites, indicating distinct Ni isotopic compositions of CI chondrites/ Ryugu compared to all other carbonaceous chondrites (Fig. 1). This is consistent with the nucleosynthetic Fe isotope variations among carbonaceous chondrites, which also reveal a uniquely distinct composition for CI chondrites and Ryugu [3].

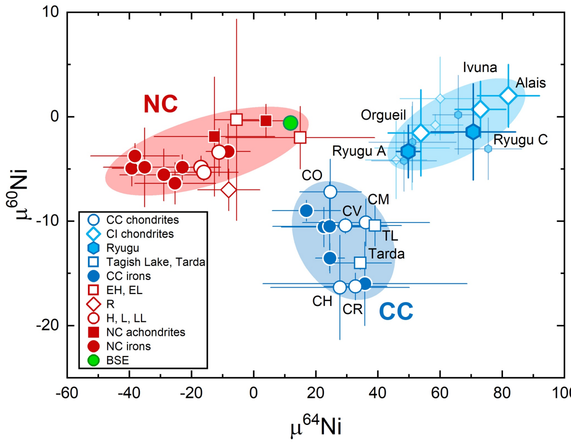

Fig. 1: $\mu^{60}Ni$ versus $\mu^{64}Ni$ for non-carbonaceous (NC) and carbonaceous (CC) meteorites. CI chondrites and Ryugu have distinct Ni isotopic compositions compared to NC and CC meteorites.

Isotopic variations among carbonaceous chondrites are thought to reflect variable proportions of three main components having distinct isotopic compositions: refractory inclusions (e.g., CAI), chondrules/chondrule precursors, and CI chondrite-like matrix [4, 5]. The incorporation of CI chondrite-like matrix in other groups of carbonaceous chondrites is consistent with systematic variations of (*i*) volatile element contents, (*ii*) mass-dependent isotope fractionations of moderately volatile elements, and (*iii*) nucleosynthetic ^{54}Cr anomalies with the fraction of matrix in each chondrite. However, in Ni isotope space, CI chondrites (and Ryugu) are offset from the composition of other carbonaceous chondrites, indicating that CI chondrites are not fully representative of the matrix in other groups of carbonaceous chondrites. Instead, this matrix appears to have formed from different precursor material than CI chondrites, either because it formed in a different area of the disk or because it was modified by processes in the disk prior to its incorporation in carbonaceous chondrites.

References

[1] Yada T. et al. 2022. Nature Astronomy 6:214–220. [2] Yokoyama T. et al. 2022. Science abn7850. [3] Hopp T. et al. 2022. Science Advances 8:8141. [4] Alexander 2019. Geochimica et Cosmochimica Acta 254:277-309. [5] Hellmann et al. 2023. Astrophysical Journal Letters 946: L34.